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AD-A223 578

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
May 1, 1990

3. REPORT TYPE AND DATES COVERED
Final Report, 1 Nov 88 to 31 Oct 89

4. TITLE AND SUBTITLE
Innovative Uses of Parallel Computers

5. FUNDING NUMBERS
AFOSR-89-0119
61102F 2304/A3

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8. PERFORMING ORGANIZATION REPORT NUMBER
AFOSR-TR 90 0735

PONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NM
Building 410
Bolling AFB, DC 20332-6448

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFOSR-89-0119

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT
One of the significant discoveries we made was primarily supported by the ONR and involves the development and extensive simulations of an original model that demonstrates the viability of the "lattice-gas" approach to hydrodynamics. Our model over-comes major difficulties of the previous discrete approaches. These difficulties can be traced to discretization artifacts that introduce a violation of the Galilean invariance and spurious energy terms in the equation of state. Some of the work done under Grant No. AFOSR-89-0119 lead us towards this theory (see publication 1). The key new element in our model (see publications 2 and 3) is the proper treatment of the energy degree of freedom (achieved by using particles with different speeds), allowing for true thermal effects. Isotropy and Galilean invariances is recovered by using adjustable direct and inverse collision rates on a projected face-centered hypercubic lattice. Extensive simulation on a Cray-2 computer of periodic shear perturbations and walks to equilibrium document correct Galileo behavior and thermalization effect.

14. SUBJECT TERMS

15. NUMBER OF PAGES
3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

AFOSR-TR- 90 ... 5

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May 1, 1990

Captain Helen R. Tyson
Air Force Office of Sponsored Research/NM
Bolling Air Force Base
Washington, DC 20332

Subject: Grant No AFOSR-89-0119, Final Technical Report

Dear Captain Tyson:

Enclosed please find our final technical report on research done under Grant No AFOSR-89-0119. The last work supported by this grant (listed below as number 7) was in fact completed last week; thus the late date of the present report.

Our research field is best described by the title of our Proposal to AFOSR: "Innovative Uses of Parallel Computers." It aims to use advanced computers in innovative ways that bypass both the numerical analysis and instabilities of floating point arithmetic. This is achieved with models which are already fully discrete, and thus lend themselves to efficient and exact simulation on digital hardware. The thrust of our effort focussed the design and implementation of models of this type for fluid dynamics (publications 1,2, and 3). We also investigated general issues of discrete modelling from the viewpoint of statistical mechanics (publication 4), programming (publication 5), and mathematical analysis (publications 6 and 7).

One of the significant discoveries ~~we~~ made was primarily supported by the ONR and involves the development and extensive simulations of an original model that demonstrates the viability of the "lattice-gas" approach to hydrodynamics. ~~Our~~ model overcomes major difficulties of the previous discrete approaches. These difficulties can be traced to discretization artifacts that introduce a violation of the Galilean invariance and spurious energy terms in the equation of state. Some of the work done under Grant No. AFORSR-89-0119 lead us towards this theory (see publication 1). The key new element in our model (see publications 2 and 3) is the proper treatment of the energy degree of freedom (achieved by using particles with different speeds), allowing for true thermal effects. Isotropy and Galilean invariance is recovered by using adjustable direct and inverse collision rates on a projected face-centered hypercubic lattice. Extensive simulation on a Cray-2 computer of periodic shear perturbations and walks to equilibrium document correct Galileo behavior and thermalization effect.

Publication 4 exhibits a new dynamical exponent in a family a cellular automata models of growth. This exponent is universal in that it can pertain to a wide class of phenomena (noise-driven metastability to instability transition). Publications 5 shows the optimized techniques for programming cellular automata under scalar, vector, and massively parallel computer architectures.

Publications 6 and 7 are of a more mathematical nature. The former studies lattice models with methods from the theory of dynamical systems, while the latter investigates the notion of Boolean derivative as a tool for bridging the discrete and continuum modelings.

1. Gérard Y. Vichniac, "Cellular Automata Fluids," in *Instabilities and Nonequilibrium Structures II,* E. Tirapegui and D. Villarroel (Eds), (Kluwer A. P., 1989).

2. K. Molvig, P. Donis, R. Miller, and J. Myczkowski, and G. Y. Vichniac, "Multi-Species Lattice-Gas Hydrodynamics," in *Cellular Automata and the Modeling of Complex Physical Systems,* P. Manneville, N. Boccara, G. Y. Vichniac, and R. Bidaux, eds. (Springer-Verlag, 1989).

3. K. Molvig, P. Donis, R. Miller, J. Myczkowski, and G. Y. Vichniac, "Continuum Fluid Dynamics from a Lattice-Gas," *submitted to Physical Review Letter.*

4. J. Myczkowski, and G. Y. Vichniac, "Critical Behavior in Cellular Automata Models of Growth," in *Cellular Automata and the Modeling of Complex Physical Systems,* P. Manneville, N. Boccara, G. Y. Vichniac, and R. Bidaux, eds. (Springer-Verlag, 1989).

5. J. Myczkowski and G. Y. Vichniac, "Parallel Programming for Cellular Automata," AICA Workshop on Parallel Programming, CINECA, Italy, *Proceedings, 1989.*

6. G. Y. Vichniac and E. Goles, "Energy and Attractors in Parallel Potts Dynamics," *MIT preprint, to appear in Journal of Physics A: Mathematical and General.*

7. Gérard Y. Vichniac "Boolean Derivatives on Cellular Automata," *to appear in Physica D, 1990.*

All the above articles aknowledge support from Grant No AFOSR-89-0119. It is our pleasant duty to acknowledge that the grant also supported in part Dr. Vichniac's participation to two meetings, where he delivered the following invited talks:

1. "Lattice-Gas Computations," First Annual Meeting of the Computational Physics Section of the American Physical Society, Boston, June 1989.

2. "Perspectives on Cellular Automata and Lattice Gases," [Panel Chair], Workshop on Lattice Gases, Los Alamos, NM, September 1989.

3. "Boolean Derivatives on Cellular Automata," Workshop on Cellular Automata, Los Alamos, NM, September 1989.

4. "Critical Behavior in Cellular Automata Models of Growth," Workshop on Cellular Automata, Los Alamos, NM, September 1989.

In the most sincere appreciation,

Gerard Vichniac

Kim Molvig

cc: Dr. A. Nachman